Real time monitoring and alert in excavation works using machine-to-machine technologies

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ABSTRACT: In high-density cities with tunnel networks and adjacent construction works, these construction sites require Real Time Monitoring and Alert systems when their movements exceed their allowable design limits. Experiences have shown that in the Nicoll Highway Collapse in Singapore, where lives were lost with huge financial consequences, the traditional automated data logging systems used were not effective in preventing site failures due to their inherent real time system design limitations. By introducing the other technologies into the existing sensor and data logger system, an Automated Real Time Monitoring and Alert system using Machine-to Machine (M2M) Technologies can provide a reliable and consistent data with a higher system uptime and require less manual maintenance effort in an Ubiquitous environment. New innovative M2M technologies of Wire-less communications, Internet and Smart Supervisory systems are used to fully automate the entire information flow chain from sensor up to the end user. This will enable the system to send the right data to the right person to make the right decision for corrective actions to be undertaken. The paper will discuss the M2M system approach and the challenges in implementing an outdoor fully automated Real Time Monitoring and Alert system.

1 INTRODUCTION

Data loggers are used for collecting real time sensor data from construction sites. The Geotechnical and Structural designers require the data for analyzing the behavior of the construction sequence and system. Normally the data are processed in days as these data are used for the verification of the design. By sharing these precious data with the construction site staff, and making the data available in Real Time for Alert, the data from these sensors can now be made into an Automated Real Time Monitoring and Alert system. The data from the same sensors and data logger on site can now be used for designers as well as construction monitoring. The site staff now can make real time judgment during the excavation process, where the reaction time is very short for remedial action.

In situations where data loggers are used for real time data collection, but not for real time monitoring and alert [1], the data loggers measure the sensor data and store them the data logger's memory at predefined intervals. This data is then retrieved every 12 or 24 hours automatically through the wire-less data communication Global System for Mobile communication (GSM) means. After the data is processed into Engineering units and analyzed, then SMS alert messages are sent out to warn users if the sensor readings exceed their alarm limits. This system cannot achieve the real time alert response time of minutes from the change in sensor readings to the mobile phones Short Message Service (SMS) alert as the time delay is limited by the time when the data is processed after being uploaded from the data loggers. Experienced reported in the Nicoll Highway incident [2,3] shows that the dial up GSM data line system can cause data transfer delays due to unavailable point to point data connections availability due to its inherent switch circuit design constraint of GSM technology.

Figure 1 illustrates an example of sensor reading for a mission critical monitoring event. The sensor is measured every hour and then stored data is uploaded to an office computer for processing and analysis at 2400 hours everyday. The computer will send out Short Message Service (SMS) alerts if the recorded data exceeds the preset trigger level. This system is a continuous data logging system but not a real time monitoring and alert system. As an illustration, when the sensor level exceeds the trigger limit at 0700 hours, no alert will be sent out. The sensor level increases progressive thereafter and reaches the allowable level at 1100 hours. The data is uploaded at 2400 hours and subsequently only then alert is sent out via SMS or email. Based on the above example, if an SMS alert is send out in real time within minutes after the reading exceeded the trigger level, 17 hours of precious time could have been used to mitigate the problem and possibly prevent deterioration of the situation. In the Nicoll Highway case, email alert were used and this made the delays even worst, as the only users with computer and Internet access will be warned. It is important to provide all users with alerts in a Ubiquitous environment using mobile phones, Pocket PCs and emails using wire-less means as most users on site are always on the move.

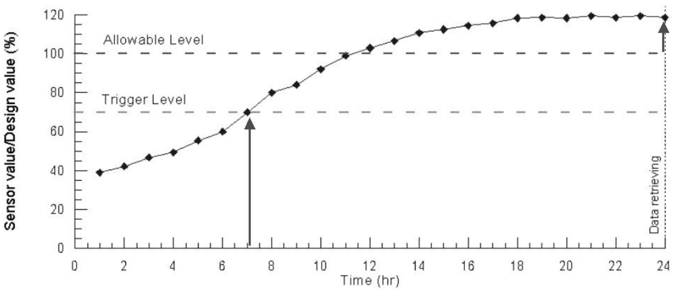

Figure 1. Time history of a critical monitoring event

If the system is required to alert users at the shortest lead time possible when the sensors exceed their limits, so that action could be taken in time, then real time monitoring and alert within minutes is important [2,4] using the pervasive wire-less technologies which are common today. This paper explains the challenges in the design and operation of the Real Time Monitoring and Alert system in Excavation works.

2 REAL TIME MONITORING AND ALERT SYSTEM

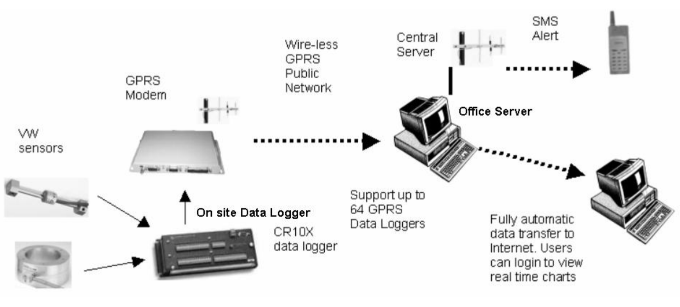

Figure 2. Data Logger with wire-less GPRS

Figure 2 shows the Real Time Monitoring and Alert system described by Ng and Tan [6] using Machine-to-Machine (M2M) technologies. In this system, a wire-less General Packet Radio Service (GPRS) modem is used to transmit the data from the data logger to the central server. GPRS is used as an always-connected data communication system. In this system, the monitoring and alert response time is in minute time scale. Real time is only meaningful when the actual sensor readings are taken and then send to the end-users in minutes. Many real time systems narrowly define the time from when the data of the office computer is send out to the end-users.

The GPRS data speed is 32,000 bps as compared to the GSM data speed of 9,600 bps, hence making it suitable for wire-less real time monitoring and alert systems. The cost for using GPRS network depends on the amount of data transfer and not on the connection time like GSM, the data logger is always be connected to the central server. Data can be transmitted between the logger and server immediately when the last channel of sensor is measured. Hence, there is no connection time delay as experienced in the GSM system. The GSM line is connected on demand whilst the GPRS is always connected on-line to the central server. The information can then be access by multiple users through the Internet. Through the use of Infocomm Technologies (IT) and Internet technologies in instrumentation and monitoring, engineers and decision makers could operate in the Ubiquitous environment and access to the real time data from their desktops, notebooks or pocket PC anytime and anywhere in the world [5,9,6].

3 THE CHALLENGES OF REAL TIME MONITORING AND ALERT SYSTEM

With Real Time Monitoring, the sensor data streams into the central server system at a high data rate. Traditional manual monitoring and alert system will experience user information overload if a manual EXCEL spreadsheet based system is used. The computer system will slow down and manually the user cannot cope up with the high data rate [2]. Hence a fully automated information flow system is a solution to overcome such a challenge.

In a Real Time Monitoring site for temporary works, the Real Time Monitoring and Alert system monitors 92 Vibrating Wire Strain Gage (VW SG) and 4 Load Cells readings every 10 minutes. Two VW SGs monitor a strut with its individual temperature sensor and the Load Cell has 4 VW SGs and 1 Temperature sensor. Hence there is a total of 92 VW+ 92T + 4 x 4 VWSG + 4 T = 1,840 sensor readings per 10 minute measurement cycle. The data rate is then 1840x 6 x 24 = 264,960 data points per day. In an EXCEL spreadsheet system, the system will be overloaded.

At this type of dynamic high-speed data rate, any sensor noise or intermittent failure will cause unnecessary alerts. There is a need for a Monitoring System Design Strategy to overcome false alert and prevent user overload. In a manual system where the readings are done twice per day, there will be 3,680 readings per day. A 0.1% false reading means 4 false alerts. For the same 0.1% false readings in 264,960 real time data, it will mean 265 false readings, which are unacceptable for Quality data. Real time monitoring and Alert system will imposed a higher expectation in the whole process of sensor installation, cabling, setup, commissioning and monitoring. The system used in a site over 18 months had 143,078,400 data collected. The total false alert readings over that period was 1,203 and they were mainly in the initial stage of familiarization by the contractor. This work out to be 8 false readings per million readings as a Quality index. As the sensors and electronics are used in outdoor environment, noise is a perpetual problem causing false SMS alerts.

Field results of Fig 3 from a site show that the VWSG readings for strut at Level 1 strut 1 have very clean readings while for those strut at Level 1 Strut 4 shows noisy VWSG readings. By compressing the time scale, these strut force readings have now been interpreted as a waveform for signal analysis where the rules of digital signal processing come into consideration. Traditionally when the user takes only a few reading per day, such time series information is not analyzed.

At every 10 minutes, the sensor readings stream in continuous. If there is a trigger event as shown in Fig 4. The system will send SMS alerts, but that point which exceeds the trigger value might be a true reading or a false trigger caused by noise. After the trigger and if the next measurement cycle exceeds the trigger limit, then the site engineers take it with more attention. However if the next cycle, the sensor readings drop, then it is classified as a false trigger. Various smart alert algorithms can be used but however the choice is always by the end users

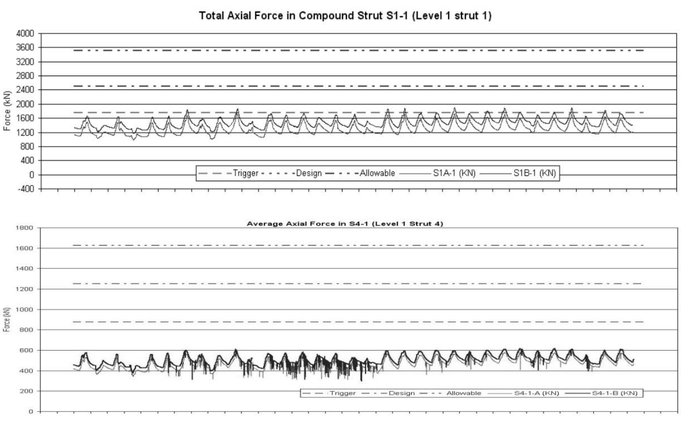

Fig 3 Strut forces time series readings over days

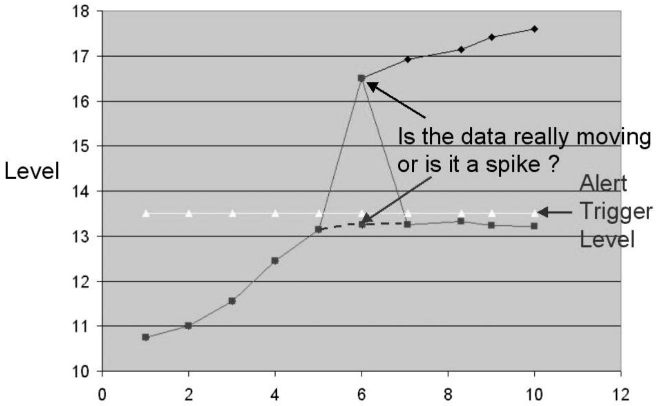

Fig 4 Strut Forces which could trigger of False Alerts

4 SOURCES OF ELECTRICAL NOISE IN READINGS CAUSING FALSE ALERTS

Noise plays a major part in the Real Time system, as any noise is pick up by the system can cause false alerts. In outdoors, these electronics components will experience voltage surges from main cables, electrical leakage and lightning voltage surges [7,8]. These can cause readings errors, computer freezes or even damage. On site when the sensor measures the data, the sensor wire travels along the site and unwanted electrical signals will interfere with the sensor wires.

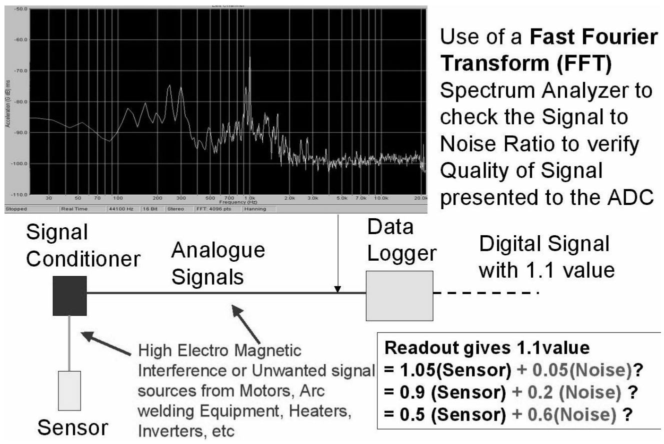

Fig 5 Noise sources causing reading errors

Unfortunately by a simple averaging technique commonly used in data loggers, the readings can have a high signal to noise ratio and still gives a readings without warning the user about the signal to noise ratio. Fig 5 shows a sensor reading of 1.1 taken from a Data logger, without knowing the signal to noise ratio, this 1.1 value can cause false alert when the actual sensor output reading is low but the noise content is high.

To help the user to trace the cause of this noise, the VW SG readings sometimes jump to high or a low SG readings even without any change in load. The cause of these reading fluctuations can be explained as high frequency noise or low frequency noise.

Fig 6 VW SG Period Counting Measurement Circuit

Typical circuit blocks of the VW SG readout circuit are shown in Fig 6. The VW SG output goes into an amplifier filter and the time taken to measure the number of cycles are recorded with a period counter circuit.

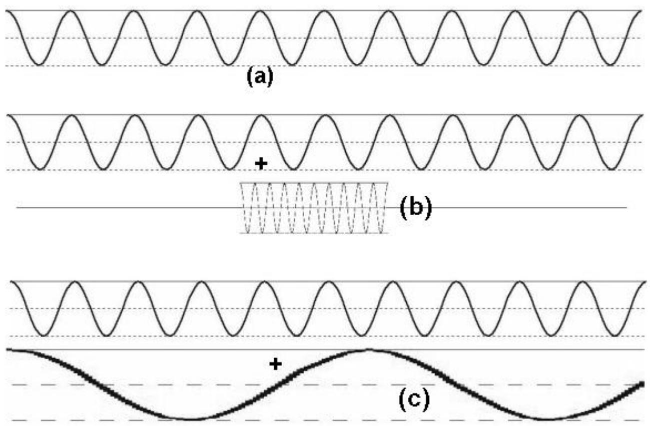

Fig 7 VW SG signals with simplified noise interference

For a simulation test, Geokon VW 4200 VW SGs were connected to a Geokon 403 Readout Box and a CR10X data logger. The noise source used for the experiment was a negative ionization generator for high frequency noise and a 50Hz demagnetizer. Fig 7 (a) waveform is injected into the circuit to get say 900Hz, an unstrained typical VW frequency. By having a VW SG signal plus a high frequency burst caused by high voltage electric surge voltages due to by capacitive cross coupling, the period counter will count the same number of cycles in a short period, giving the readout box or data logger as a higher frequency reading of say 1,200 Hz. Fig 7 (b) shows the combination of the VW SG 900Hz plus the higher frequency noise burst. Fig 7 (c) shows the next interference waveform with magnetic 50Hz field overload, due to mains currents, the waveform gets overload at the peaks and dips of the 50Hz such that the counter gets saturated and cannot count the particular cycles in the 900Hz signal. The counter then will take a longer period to count the same number of cycles. This in turn is interpreted as a lower frequency VW SG reading of say 700 Hz.

As the application of electronics, signal processing and communication increases in the traditional civil engineering sector, the improvements of the automated instrumentation will require a multi-disciplines approach such as Structural, Geotechnical, Electronics, Communication and Computer Engineering expertise to collaborate as a team to overcome the new, more complex Real Time Monitoring requirements to make the construction site a safer place to work.

5 BENEFITS OF REAL TIME MONITORING SYSTEM

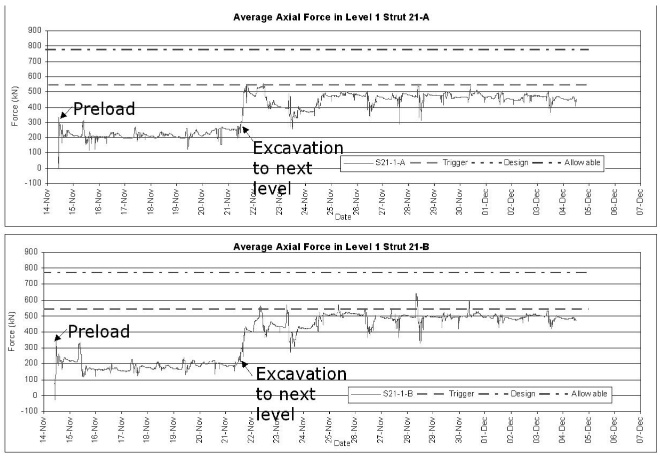

Fig 8 Real Time Strut Forces changes with excavation depth

The main advantage of the Real Time Monitoring and Alert system is obviously the Real Time alert where the site staff gets urgent data instantly when sensors exceed their limits. The other benefit is to provide the users and designers the actual on-site forces acting on the struts when construction work progresses as shown in Fig 8. This increases the productivity of the Geotechnical consultants by having their verification of the design via the Internet instead of visiting the site, which could be hours drive away. This brings the important site data to the desktop of the designer via communication technologies, hence reducing the unproductive time of traveling to site to retrieve data.

In another Real Time monitoring system, the results help the bridge designers to verify their post –tension forces. Fig 9 shows the mounting VW SG to measure the relative change of strain during the process. The real time monitoring is done every 10 minutes so that the slower thermal effect does not take into account yet. The results in Fig 10 show of the strain movements and discriminate temperature effect as the thermal effect takes hours to change the strain while the post tensioning process is done within minutes. In this field test, 18 VW SGs and 1 Temperature sensor are mounted onto the bridge and recorded during the post tension process. The data is logged every 10 minutes and send back to a website for computation for sensor calibration into $\mu\varepsilon$. Real time is used so that the effect of strain changes during the post tensioning can be tracked continuously. The results show that the strain values do change with respect of the post tension timings. The temperature strain readings show a slower change over time.

Fig 9 VW SG mounted onto surface of bridge

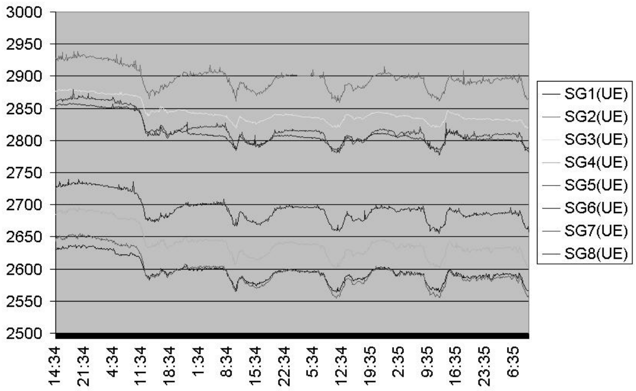

Fig 10 Relative change in strain over time

6 CONCLUSIONS

Data Loggers have been used in monitoring systems for many years, especially for projects, which required continuous monitoring. They are mainly used for design verification, monitoring, investigation works and research. Using M2M technologies of wireless communications, Infocomm Technologies and Internet, these monitoring systems have evolved into mission critical civil engineering applications where the information are needed in a matter of minutes rather than hours. Using available technologies, Mission critical Real Time Monitoring and Alert systems are used to monitor and deliver information from the sensor until the end users in minutes. When the sensor readings exceed their predefined limits, the system automatically sends SMS alerts to multiple users within minutes. The system delivers the important information onto the mobile phones of the users. This compression of the total delivery time, from the remote site sensor to the user, is useful to inform site problems immediately for critical projects. It gives users more reaction time to organize, to investigate and to prevent collapses or failures rather than having data to confirm that the site had problems. With the wider acceptance of M2M technologies by the consumer sector, the relevant technologies have become easily accessible for wider deployment in the civil engineering sector. This forms a new cluster of mission critical monitoring and real time alert systems based upon the M2M technologies.

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